Scenario And Probabilistic Maps Of Ground Motions That Account For Site Effects, Basin Effects, Duration Of Shaking And Rupture Directivity In The San Francisco Bay Area

USGS Award No.: 1434-HQ-98-GR-0026

Paul G. Somerville
Woodward-Clyde Federal Services
566 El Dorado Street
Pasadena CA 91101

Tel: 626-449-7650
Fax: 626-449-3536

Program Element: II

Key Words: Evaluate Urban Hazard and Risk

Investigations undertaken

We are currently making ground motion maps for the scenario earthquakes listed in Table 1. These maps include rupture directivity, site effects, and the effects of shallow basin structures on the amplitude and duration of ground motions. In addition to these scenario maps, we are also generating probabilistic ground motion maps. These maps will be similar to the NEHRP maps generated jointly by CDMG and USGS for soft rock/dense soil site conditions, except that they will include site effects, basin effects, and rupture directivity effects. We are also generating maps with and without rupture directivity effects for rock/dense soil site conditions, to determine whether directivity effects have a significant effect on the maps.

Table 1. List of San Francisco Bay Area Earthquake Scenarios

FAULT SYSTEM	FAULT SEGMENT
San Andreas	Golden Gate, San Francisco Peninsula
Hayward	Rodgers Creek, Northern East Bay, Southern East Bay

Results

The development of models of the 3D seismic velocity structure in the San Francisco Bay area by Brocher et al. (1997) and Antolik et al. (1997) has led to rapid progress in understanding the potential effects of laterally varying crustal structure on strong ground motions in the Bay area. In Figure 1, we show the results of preliminary calculations of peak velocity from a magnitude 6.75 earthquake rupturing to the southeast on the northern segment of the Hayward fault. These calculations were done on a workstation using a finite difference code (Graves, 1995; Pitarka, 1998). Comparison of the results obtained using a flat layered (1D) model with those using the 3D model of Brocher et al. (1997) indicates that the effect of the laterally varying structure is generally moderate in the densely urbanized regions. The main differences occur to the east of the Hayward fault beneath the coast ranges, and along the southeastern shore of San Francisco Bay. The ground motions for the 3D model in these regions are significantly larger than those for the flat layer model at periods longer than about one second.

The predominantly strike-slip mode of faulting in the Bay area has not generated a large degree of subsidence and basin filling beneath these regions; the deepest basin lies east of the Hayward fault. The conditions that gave rise to extremely large basin edge effects in the Kobe earthquake (Pitarka et al., 1998) and in Santa Monica during the 1994 Northridge earthquake (Graves et al., 1998), which are rapid lateral variations in seismic velocity across basin-bounding faults, may not be prevalent in the Bay area. Further, most locations within the Bay area are no more than 10 km from a major strike-slip fault. This indicates that the most critical ground motion phenomenon associated with the major strike-slip faults in the Bay area is that due to rupture directivity.

We previously developed an empirical model for the effects of rupture directivity on the response spectral amplitudes and durations of near-fault ground motions (Somerville et al., 1997). Preliminary probabilistic seismic hazard calculations 2 km from the Hayward fault (Figure 2) show that for ground motion periods that are important for tall buildings (about 2 seconds), applying this directivity model to a standard attenuation relation (Abrahamson and Silva, 1998) increases the spectral acceleration by 30% for the average horizontal component, and the fault normal component is 70% larger, at the annual probability of exceedance of $4x10^{-4}$ which is the underlying basis of design levels in the 1997 NEHRP Provisions. Both the 1997

UBC and the 1997 NEHRP Provisions use ad-hoc methods of prescribing near-fault ground motion levels. The inclusion of rupture directivity effects provides a more rational basis for prescribing near-fault ground motions in these codes, and should be incorporated into the next revision of the USGS National Seismic Hazard Maps for use in the IBC.

Non-technical Summary

The objective of this project is to generate ground motion maps that account for rupture directivity effects, basin effects and site effects in the San Francisco Bay area. For an earthquake on the Hayward fault, the main effect of the sedimentary basins on ground motions in the San Francisco Bay is to increase the ground motions east of the Hayward fault beneath the coast ranges, and along the southeastern shore of San Francisco Bay. The most critical ground motion phenomenon associated with the major strike-slip faults in the Bay area is that due to rupture directivity. Applying a model for rupture directivity to the calculation of probabilistic ground motions such as those in the NEHRP ground motion maps increases the long period ground motions significantly.

References

Abrahamson, N.A. and W.J. Silva (1997). Empirical response spectral attenuation relations for shallow crustal earthquakes. *Seismological Research Letters* 68, 94-127.

Graves, R. W., A. Pitarka, and P. G. Somerville (1998). Ground motion amplification in the Santa Monica area: effects of shallow basin edge structure, *Bull. Seism. Soc. Am.*, 88, 337-356.

Graves, R. W. (1996). Simulating seismic wave propagation in 3D elastic media using staggered-grid finite-differences, *Bull. Seism. Soc. Am.*, 86, 1091-1106.

Graves, R.W. (1993). Modeling three-dimensional site response effects in the Marina District Basin, San Francisco, California. *Bull. Seism. Soc. Am*. 83, 1042-1063.

Pitarka, A., K. Irikura, T. Iwata and H. Sekiguchi (1998). Three-dimensional simulation of the near-fault ground motion for the 1995 Hyogo-ken Nanbu (Kobe), Japan, earthquake. *Bull. Seism. Soc. Am.*, 88, 428-440.

Pitarka, A. (1998) 3D elastic finite-difference modeling of seismic wave propagation using staggered-grid with variable spacing (manuscript in preparation).

Somerville, P.G., N.F. Smith, R.W. Graves, and N.A. Abrahamson (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity, *Seismological Research Letters* 68, 180-203.

Simulated Peak Velocity (0.1-0.8 Hz)

M6.75 Hayward Fault Scenario

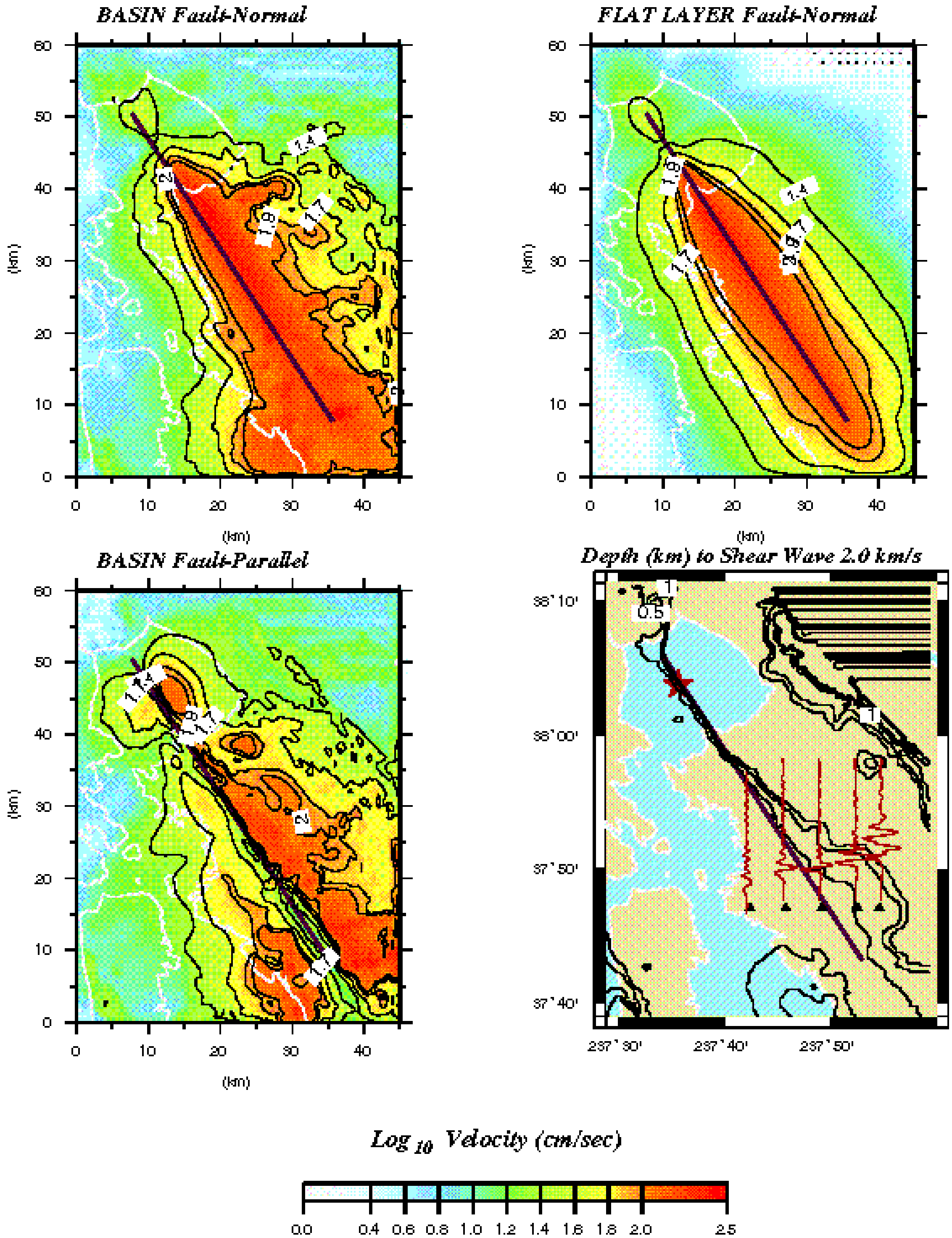

Figure 1. Comparison of peak velocity in the east San Francisco Bay area from a magnitude 6.75 earthquake on the Hayward fault calculated for a flat layer (1D) model (right) and 3D model Brocher et al.,1997 (left). The contours of depth to shear wave velocity of 2.0 km/s are shown on the map to the lower right, together with velocity seismograms across Oakland. The earthquake ruptures to the southeast from the epicenter (star).

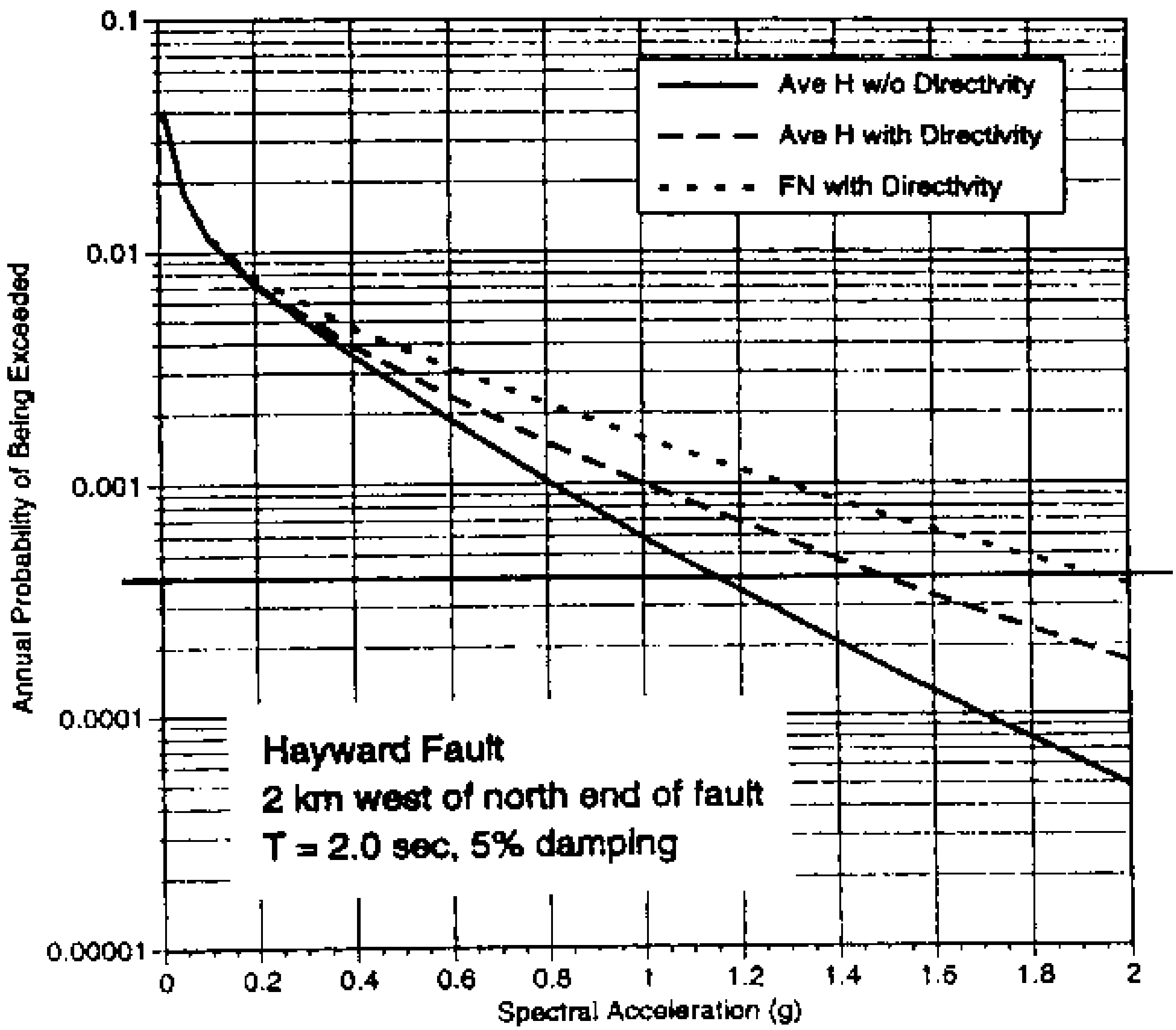

Figure 2. Probabilistic ground motion hazard curves fro 2 second spectral acceleration at a site 2km from the Hayward fault. Including the directivity model of Somerville et al.,1997 (dashed line) increases the average horizontal component above that for the conventional

attenuation relation (solid line); the fault normal component (dotted line) is still larger.
